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Submitted by:
Présenté par: J.P. Komorowski
Director/Directeur

Approved by:
Approuvé par: D.L. Simpson
Director General/Directeur général

Author(s): Nirmal K. Sinha
Auteur(s):

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RUNWAY SURFACE AND ENVIRONMENTAL CONDITIONS DURING FRICTION TESTS AT K.I. SAWYER AIRBASE, MICHIGAN, USA – FEBRUARY 1999

Prepared for
Transportation Development Centre
and
Aerodrome Safety Branch
of
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By

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Runway Surface and Environmental Conditions During Friction Tests at K.I. Sawyer Airbase, Michigan, USA – February 1999

By

Nirmal K. Sinha
National Research Council Canada

September 2000

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The Transportation Development Centre and the sponsoring organization do not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract

The Joint Winter Runway Friction Measuring Program (JWRFMP) was extended to include trials at K.I. Sawyer Airbase in Gwinn, Michigan, USA, during the week of February 1-7, 1999. Five ground friction measuring devices from Canada, France, UK and USA were assembled and used at K.I. Sawyer Airbase. During the week, one instrumented commercial passenger aircraft, a Boeing B757 belonging to NASA, also participated in the tests. This report contains information on environmental conditions during the tests and surface contaminants collected during the tests. Natural contaminants included freshly fallen snow as well as old accumulated snow.

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16. Résumé

La portée du Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH) a été élargie de façon à englober les essais réalisés à la base aérienne K.I. Sawyer, à Gwinn, au Michigan (É.-U.), du 1er au 7 février 1999. Au total, cinq appareils de mesure du frottement au sol du Canada, de la France, du Royaume-Uni et des États-Unis ont été réunis aux fins des essais à la base aérienne K.I. Sawyer. Pendant la semaine, un avion commercial de passagers instrumenté, soit un B757 appartenant à la NASA, a aussi pris part aux essais. Le présent rapport comprend des renseignements sur les conditions environnementales dans lesquelles se sont déroulés les essais et sur les contaminants présents sur les pistes. Au nombre des contaminants naturels qui se trouvaient sur la chaussée, on retrouvait de la neige fraîche et de la vieille neige accumulée.

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EXECUTIVE SUMMARY

A five-year project was initiated in December 1995 to understand and to quantify the factors that influence aircraft braking friction and the contamination drag of various aircraft on winter contaminated runways, in order to estimate landing or take-off distances on wet and winter contaminated runways. A collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using variously instrumented aircraft and ground friction measuring vehicles. The U.S. Federal Aviation Administration (FAA), National Research Council Canada (NRC) and organizations from other countries (e.g., the Norwegian Civil Aviation Administration) eventually joined this program, which is now called the Joint Winter Runway Friction Measurement Program (JWRFMP).

Following field tests at North Bay Airport in North Bay, Ontario, Canada in January 1999, JWRFMP was extended to include trials at K.I. Sawyer Airbase in Gwinn, Michigan, USA, during the week of February 1-7, 1999. Five ground friction measuring devices from Canada, France, UK and USA were assembled and used at K.I. Sawyer Airbase. These included the Surface Friction Tester (SFT) and Electronic Recording Deceleronmeter (ERD) from Canada, the Instrument de Mesure Automatique de la Glissance (IMAG) from France, the Instrumented Tire Test Vehicle (ITTV) from the USA and the GripTester (GT) from the UK. During the week, one instrumented commercial passenger aircraft, a Boeing B757 belonging to NASA, also participated in the tests. This report concerns information on environmental conditions during the tests and surface contaminants collected during the tests. Natural contaminants included freshly fallen snow as well as old accumulated snow.

The low volume of commercial air traffic and the long (3700 m) and wide (20 m or more) uniform asphalt concrete surface of the movement area (taxiway and runway) at K.I. Sawyer Airbase provided an ideal, textbook-type platform for conducting vehicular tests on a winter contaminated surface. Tests could be performed with a number of vehicles at the same time, running on different tracks parallel to each other. This avoided the condition of running the vehicles in sequential manner on previously travelled and disturbed surfaces. One series of tests involving three ground friction devices – IMAG, GT and SFT – and (incidentally) the aircraft, conducted on freshly fallen snow, proved the real possibility of conducting such parallel tests. No such tests had ever been performed in the past three years of runway friction tests. The tests showed that the degree of compaction (96%) produced by the IMAG test tires (at 40 km/h) was comparable to that (98%) developed by the tires of the slowly moving (≈ 10 km/h) aircraft main gear. At the speed of 40 km/h, the SFT and the GT produced 74% and 44% compaction, respectively.

K.I. Sawyer Airbase is a unique facility and should therefore be used in future runway friction testing.

SOMMAIRE

En décembre 1995, on lançait un projet quinquennal visant à mieux comprendre et à quantifier les facteurs ayant une incidence sur le rendement au freinage des avions et l'effet de la traînée causée par la contamination des pistes sur différents types d'avions, afin d'établir les distances de décollage et d'atterrissage sur pistes mouillées ou contaminées. Une entente de collaboration a été conclue entre la National Aeronautics and Space Administration (NASA) et Transports Canada (TC) pour la réalisation d'essais en vraie grandeur, à l'aide d'avions diversement instrumentés et de véhicules de mesure du frottement au sol. La Federal Aviation Administration (FAA) des États-Unis, le Conseil national de recherches du Canada (CNRC) et d'autres organismes étrangers (p. ex., l'Administration de l'aviation civile de Norvège), se sont progressivement joints au programme, qui se nomme maintenant Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH).

Par des essais sur le terrain réalisés à l'aéroport de North Bay, à North Bay, en Ontario, Canada, en janvier 1999, la portée du PCRGCAH a été élargie afin d'englober des essais menés du 1er au 7 février 1999 à la base aérienne K.I. Sawyer de Gwinn, au Michigan (É.-U.). Au total, cinq véhicules de mesure du frottement au sol provenant du Canada, de la France, du Royaume-Uni et des États-Unis ont été réunis aux fins des essais. Ces véhicules étaient le glissancemètre de Saab (SFT) et le décéléromètre électronique (ERD) du Canada, l'Instrument de mesure automatique de la glissance (IMAG) de France, l'appareil ITTV (pour *Instrumented Tire Test Vehicle*) des États-Unis et le GripTester (GT) du Royaume-Uni. Pendant la semaine, un Boeing B757 instrumenté appartenant à la NASA a aussi pris part aux essais. Le présent rapport comprend des renseignements sur les conditions environnementales dans lesquelles se sont déroulés les essais et sur les contaminants présents sur les pistes. Au nombre des contaminants naturels qui recouvraient la piste, on retrouvait de la neige fraîche et de la vieille neige accumulée.

Le faible volume du trafic aérien, combiné à une aire de mouvement (voie de circulation et piste) recouverte d'une couche de béton asphaltique uniforme de 3 700 m de longueur et d'au moins 20 m de largeur, faisait de la base aérienne K.I. Sawyer l'endroit tout désigné pour réaliser des essais de frottement sur des chaussées contaminées par des précipitations hivernales. En effet, il était possible d'y effectuer plusieurs essais simultanés au moyen de différents véhicules évoluant parallèlement les uns aux autres, plutôt que de lancer les véhicules de façon séquentielle sur des chaussées perturbées par le passage des véhicules précédents. L'une des séries d'essais réalisés au moyen de trois appareils, soit l'IMAG, le GT et le SFT (ainsi que l'avion), sur de la neige fraîche, a démontré la possibilité réelle de mener des essais simultanés en parallèle. Au cours des trois dernières années d'essais de glissance des chaussées, aucun essai de ce genre n'avait été entrepris. Les essais ont révélé que le degré de tassement (96 %) produit par les pneus de l'IMAG (à 40 km/h) était comparable à celui (98 %) des pneus du train d'atterrissage d'un avion roulant lentement, à environ 10 km/h. À une vitesse de 40 km/h, les taux de tassement produits par le SFT et le GT étaient de 74 % et de 44 %, respectivement.

La base aérienne K.I. Sawyer est une installation unique et elle devrait donc être utilisée pour les prochains essais sur la glissance des chaussées aéronautiques.

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GLOSSARY OF TERMS

d	Idealized depth of compacted snow
D	Depth of natural snow cover
DND	Canadian Department of National Defence
ERD	Electronic Recording Decelerometer (in a Blazer)
FAA	U.S. Federal Aviation Administration
GT-STD	GripTester - Standard
IMAG	Instrument de Mesure Automatique de la Glissance
IRFI	International Runway Friction Index
ITTV	Instrumented Tire Test Vehicle (NASA, Langley Research Center)
JWRFMP	Joint Winter Runway Friction Measurement Program
LDG	Landing
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
p	Idealized space between compacted snow and displaced snow
ρ_c	Compacted density
ρ_n	Natural density
RTO	Rejected Take-off
SFT	Saab Surface Friction Tester
TC	Transport Canada
TDC	Transportation Development Centre of Transport Canada
TO	Take-off
w	Idealized width of compacted snow

1 INTRODUCTION

1.1 Background

In December 1995, a five-year project was initiated to understand and to quantify the factors that influence the aircraft braking friction and contamination drag of various aircraft on winter contaminated runways in order to estimate landing or take-off distances on wet and winter contaminated runways. A collaborative agreement was made between Transport Canada (TC) and the National Aeronautics and Space Administration (NASA) to conduct field tests using different types of instrumented aircraft and ground friction measuring vehicles. The U.S. Federal Aviation Administration (FAA) and National Research Council Canada (NRC) also joined this project as additional collaborating agencies. This was known as NASA/FAA/TC/NRC winter runway aircraft operation and surface friction measuring program. The Canadian Department of National Defence (DND), several organizations from other countries (the Norwegian Civil Aviation Administration, for example) and several airframe and ground friction measuring equipment manufacturers eventually joined the program, which is now called the Joint Winter Runway Friction Measurement Program (JWRFMP).

Considerable efforts have been expended over the past several years to understand the correlation between the friction factors measured by the ground vehicles or devices on runways and the friction coefficients derived from the performance of aircraft operating on runways [1, 2, 3, 4, 5, 6]. JWRFMP has gained increasing international support and recognition, and stakeholders are working cooperatively towards an approved International Runway Friction Index (IRFI) based on the most accurate and comprehensive data possible [1].

The first three years of testing were conducted at North Bay airport in North Bay, Ontario, Canada, during the winters of 1995-1996, 1996-1997 and 1997-1998. These three series of field tests were successful in providing initial comparative data between four different types of aircraft (the NRC Falcon 20, the NASA B737, the FAA B727 and the deHavilland Dash 8) and several ground friction measuring devices. During the winter of 1997-98, ground vehicle testing was also conducted, in addition to North Bay trials, at the specially made test tracks beside the main runway of the newly constructed Oslo International Airport in Norway.

The first phase of the 1998-99 JWRFMP tests were carried out in North Bay in January 1999. The second phase of that winter's tests was extended to include K.I. Sawyer Airbase near Gwinn, Michigan, USA, from February 1-7, 1999. This airport is situated on the east side of Highway 553 about 25 km south of the city of Marquette. The nearest town is Gwinn, about 10 km away. NASA's newly instrumented B757 test aircraft and five test vehicles, the Instrumented Tire Test Vehicle (ITTV), the Instrument de Mesure Automatique de la Glissuance (IMAG), the Saab Surface Friction Tester (SFT), the GripTester (GT) and the Electronic Recording Decelerometer (ERD), participated in this phase.

1.2 Objectives and Scope

The test objectives for the ground friction measuring vehicles were primarily to assess the effectiveness of these devices on various winter contaminated runway surfaces, and to standardize their outputs into an International Runway Friction Index (IRFI). One of the main objectives of K.I. Sawyer Airbase tests was to compare the output of a few ground friction measuring devices to the results obtained from NASA's newly acquired and instrumented Boeing B757 aircraft. Ground vehicles or devices that participated under this objective were those that were harmonized in previous field tests in 1997 and 1998. Five ground vehicles or devices from different countries were assembled and used at K. I. Sawyer Airbase during the week of February 1-7, 1999.

The results of the aircraft tests will be published in a separate report and will not be referred to in this report. The results of ground friction measuring devices are presented here together with the observations made on the environmental conditions during the test period. This report contains mainly information on the characteristics of surface contaminants and environmental conditions during the test period collected during the tests carried out at K.I. Sawyer airbase during the week of February 1-7 1999.

2 TEST PROGRAM

2.1 Ground Vehicles

The following five ground vehicles (devices) were used to conduct contaminated surface friction measurements during the test period.

IMAG	Instrument de Mesure Automatique de la Glissuance
ERD	Electronic Recording Decelerometer in a Blazer from Transport Canada
SFT	Saab Surface Friction Tester – from Transport Canada
GT	GripTester – from U.K.
ITTV	Instrumented Tire Test Vehicle – from NASA, Langley Research Center, USA

The Transport Canada ERD mounted in a Chevrolet Blazer was used as one of the standard devices because of the correlation already established earlier with NRC's Falcon 20 aircraft. The ERD was used extensively at K.I. Sawyer Airbase in evaluating the conditions of the runway surfaces in the stopping distance in front of the designated test site for the aircraft as well as the two sides of the test bed. The B757 pilots used the ERD data for their decision-making processes.

2.2 Test Facility

The K.I. Sawyer Airbase authority provided the flight operation area of the entire 01-19 runway (3749 m x 46 m) and the taxiways parallel to the main runway for this operation (Figure 1 a,b). One of the hangers was used as the home base of the operation for the aircraft. The old terminal building, which was empty at the time of these tests, was used as the base camp of the test headquarters. This provided not only the required office spaces for the operation and the briefing room for the participants, but also an easy access to the ground vehicles used for the tests. The briefing room was well equipped with telephones, a photocopier and a fax machine. The facilities were excellent.

The runway was made of asphalt concrete that was old, but in fair condition. Because of its size and practically non-operational conditions, except for a few local flights per day by small aircraft (which used only a tiny section of the huge runway), the airbase provided ample space and free time for testing and was therefore an ideal base for conducting the runway friction tests.

A fleet of ploughs, trucks and snow blowers was used to clean the surfaces of the movement area and prepare the contaminated surfaces on the designated site for aircraft tests.

Video recording and still photography were used. A team of two photographers from the NASA, Langley Research Center in Hampton, Virginia, participated in this field program. Video recordings were also made for every aircraft run by a camera mounted on the aircraft. In addition to this, the author took photographs that are used in this report.

3 OBSERVATIONS

Observations made on the environmental conditions and characteristics of the contaminants on the test strip are given on a daily basis in a chronological manner. An attempt was also made here to link the author's observations with the test numbers, the ground friction data and the test flight runs, but this was not always possible because of unavoidable technical difficulties due to logistics.

Still photographs were taken to keep records of the ever-changing characteristics of the contaminants and the interaction processes between the contaminants, the aircraft and ground vehicle tires. These were taken in an almost continuous manner during most of the tests. The ground-level and aircraft-mounted video recordings, and the still photographs taken by the NASA photographer, who worked closely with the author during most of the tests, have been retained by NASA Langley Research Center.

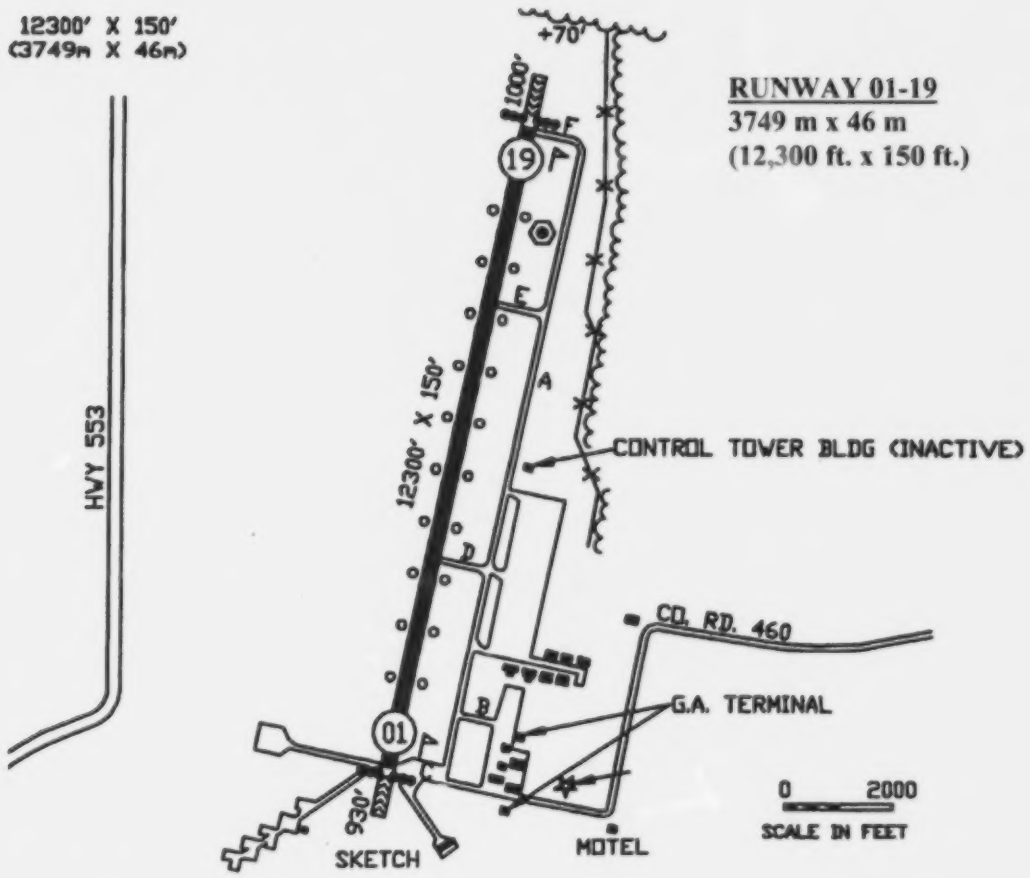


Figure 1a. General view of the K.I. Sawyer Airbase, Gwinn, Michigan, USA

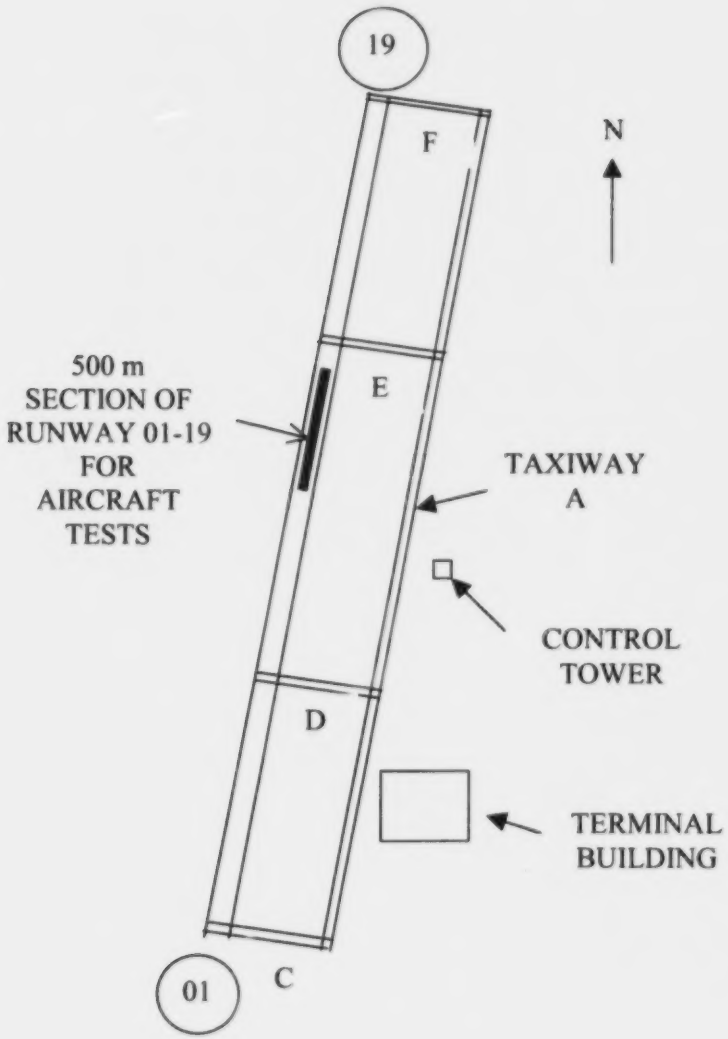


Figure 1b. View of the test sites showing the 500 m x 15 m section of the runway (01-19) on the left and the taxiway (A) on the right

3.1 Sunday 31 January and Monday 1 February 1999

These two days were used mainly for the arrival of the test vehicles, setting up the base, and conducting some preliminary ground friction tests for device calibrations and check out.

The author left his home in Ottawa on Sunday 31 January at 11:30 and had to take the Ottawa/Detroit/Marquette air route to reach the destination closest to the test site at about 02:00 on Monday 1 February. Because of this odd arrival time, he was not present at K.I. Sawyer Airbase during the day when the NASA Boeing B757 test aircraft arrived there and performed two preliminary tests (Flight No. R092) with landing configuration. Run 1 was a 60 kn tare run and Run 2 a 60 kn braking run. To the author's knowledge, no environmental information for K.I. Sawyer Airbase was recorded for the above tests except for the observation that the snow on the runway test section was 58 mm in depth.

In Marquette, however, it was a cloudy and windy morning. The cloudy and windy conditions persisted through the night, and the wind picked up significantly during the early morning hours of Monday 1 February. However, the sky started to clear partially during the morning and the wind speed decreased. At 07:00, the air temperature, T_A , was –5°C. It was a relatively calm morning with a SSW wind at 13 km/h. As the day progressed, a thick cloud cover started to move in and the ceiling dropped dramatically to about 180 m. The air temperature increased to –2°C at 14:00. and the speed of the SSW wind decreased to about 10 km/h. The relative humidity was 85% at this time and some snow flurry activities started as well. The local weather pattern at Marquette changed to freezing drizzle by the evening, whereas the conditions at the test site of K.I. Sawyer airbase changed to light snow with practically no wind. Because of the prevalent SSW wind direction, the snowing activities eventually reached Marquette during the night.

3.2 Tuesday 2 February 1999

It snowed lightly most of the early morning hours of Tuesday and there was a layer of 10 mm of snow on the ground. When the author left Marquette at 07:00 by car, it was snowing there and the local weather conditions were as follows:

T_A = –0°C, Wind = SSW 11 km/h, Visibility = 6 km
Ceiling = 150 m, Relative Humidity = 89%

Immediately after the author's arrival at the airport, at about 08:10, an inspection of the taxiway and the main runway, 01-19, was made. The snow cover on the runway had not been disturbed during the night's snowfall activities. Consequently, the entire 46 m wide and 3749 m long pavement of the runway was covered with an extremely uniform undisturbed freshly fallen snow cover – an ideal test condition. At the surface level, the snow particles were flaky with diameters as large as 5 mm. A number of measurements of snow thickness and the thickness profile of the snow cover across the width of the runway were made. Three specimens were also recovered for density measurements from

the two ends and the middle of the designated 500 m long section on the runway between Bravo and Charlie. The details are given in Table 1a.

Table 1a. Characteristics of freshly fallen snow on runway 01-19 at K.I. Sawyer Airbase during the morning of 2 February 1999 corresponding to Test 9933.1A

Runway	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
01-19	08:30	18	127	-0.6	+0.8
	08:40	18	111	-0.5	+0.8
	09:45	18	116	-0.6	+0.8
			Average: 118		

Note: The moisture content of snow was about 3%. The snow thickness profile across the width of runway 01-19 was uniform. The average thickness was 18 mm ± 2 mm

Soon after finishing the snow measurements, vehicular tests started on the snow-covered pavement near the south end, or 01-end, of runway 01-19. At this end, the snow cover on the runway pavement was not as uniform as it was at the designated area of aircraft tests described above. There were some measurable variations in the snow thickness. It varied between 13 mm and 19 mm, with an average of about 18 mm. Five ground vehicles took part in this series of friction tests: the SFT, GT, IMAG, ITTV and ERD. Figure 2 shows four of these five test devices at K.I. Sawyer Airbase. This test series was abruptly stopped at 09:05 because of the imminent landing of a commercial aircraft on the runway. The test results are tabulated in Table 1b for Test 9933.1A.

(a)

(b)

(c)

(d)

Figure 2. IMAG (a), ERD (b), SFT (c) and ITTV (d) used at K.I. Sawyer Airbase

Table 1b. Friction test results reported by the ground test vehicles for Test 9933.1A of 2 February on the south end of runway 01-19

TEST: 9933.1A

Date: 99/02/02 **Air Temperature:** +0.8°C
Time: 08:45 - 09:05 **Facility:** 01-19
Test Location: 01 End **Length of Test Strip:** 300 m
Surface Conditions: Loose moist (moisture content of about 3%) snow (13 to 19 mm) at –0.6°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65	1	0.20	0.24	0.32		
	2	0.20	0.24	0.31		0.30
	3	0.20	0.24	0.31		0.28
	Average	0.20	0.24	0.31		0.29
65	1	0.20	0.24	0.29		0.28
	2	0.20	0.24	0.30		0.30
	3	0.19	0.24	0.30		0.31
	Average	0.20	0.24	0.30		0.30
50	1	0.19	0.24	0.30		0.31
	2	0.19	0.24	0.30		0.28
	3	0.19	0.24	0.29		0.29
	Average	0.19	0.24	0.30		0.29
50	1	0.19	0.24	0.29		0.26
	2	0.19	0.24	0.30		0.29
	3	0.19	0.24	0.29		0.28
	Average	0.19	0.24	0.29		0.28
40	1	0.18	0.24	0.29		0.30
	2	0.18	0.23	0.28		0.25
	3	0.18	0.24	0.28		0.25
	Average	0.18	0.24	0.28		0.27
40	1	0.16	0.22	0.27		0.23
	2	0.15	0.22	0.26		0.24
	3	0.15	0.22	0.26		0.24
	Average	0.15	0.22	0.26		0.24

Note: Tire pressures are given in psi and the conversion factor is 145 psi = 1 MPa

Vehicular tests resumed soon after the control tower gave permission to use the runway again. Since the condition of snow was disturbed at the previous site, it was decided to move the location for the next series of tests to a new site at 09:20. This was on the eastern shoulder of the main runway 2000 to 3000 ft. from the 01 end. Two snow samples were taken from areas near the two ends of this 300 m long test section. Here the snow cover was significantly thicker (30 mm) and lighter (density of 94 $kg.mm^{-3}$) than that on the major part of the runway (Table 2a). The results of friction tests are given in Table 2b.

Table 2a. Characteristics of freshly fallen snow on runway 01-19 at K.I. Sawyer Airbase during the morning of 2 February 1999 corresponding to Test 9933.1B

Runway	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
01-19	09:20	30	94	-0.5	+0.6
	08:30	30	94	-0.5	+0.6
			Average: 94		

The introductory meeting with the crew of NASA's B757 test aircraft took place between 10:00 and 11:30. During this meeting, heavy cloud cover started to move eastward and it started to snow. After the welcome and general meeting, vehicular tests were conducted from 12:10 to 12:35 on a 1200 m long test strip near the west bank of the north end of taxiway A between E and F (see Figure 1b). A large number of snow thickness measurements were carried out along the width and length of this strip. The snow cover was very uniform and the thickness varied from a minimum of 38 mm to a maximum of 46 mm. During this period snow continued to fall intermittently.

Table 2b. Friction test results reported by the ground test vehicles on the south end of runway 01-19

TEST: 9933.1B

Date: 99/02/02 **Air Temperature:** +0.6°C
Time: 09:25 - 9:45 **Facility:** 01-19
Test Location: 01 end **Length of Test Strip:** 300 m
Surface Conditions: Loose moist (moisture content of about 3%) snow (30 mm) at –0.5°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65	1	0.13	0.22	0.27		0.27
	2	0.13	0.22	0.27		0.27
	3	0.13	0.22	0.25		0.28
	Average	0.13	0.22	0.26		0.27
65	1	0.13	0.22	0.27		0.25
	2	0.13	0.22	0.27		0.25
	3	0.13	0.22	0.26		0.28
	Average	0.13	0.22	0.27		0.26
50	1	0.13	0.22	0.26		0.24
	2	0.13	0.21	0.26		0.22
	3	0.13	0.21	0.25		0.26
	Average	0.13	0.21	0.26		0.24
50	1	0.13	0.21	0.26		0.25
	2	0.13	0.21	0.26		0.23
	3	0.13	0.21	0.25		0.26
	Average	0.13	0.21	0.26		0.25
40	1	0.13	0.20	0.26		0.24
	2	0.13	0.20	0.25		0.21
	3	0.13	0.20	0.25		0.21
	Average	0.13	0.20	0.25		0.22
40	1	0.13	0.20	0.25		0.24
	2	0.13	0.21	0.24		0.21
	3	0.13	0.20	0.24		0.21
	Average	0.13	0.20	0.24		0.22

Table 3a. Characteristics of freshly fallen snow on taxiway A at K.I. Sawyer Airbase during the noon hour of 2 February 1999 corresponding to Test 9933.3

Taxiway	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
A	12:00	43	104	-0.4	+0.8
A	12:15	43	106	-0.4	+0.8
			Average: 105		

Table 3b. Friction test results reported by the ground test vehicles on the north end of taxiway A during the noon hour of 2 February 1999 for Test 9933.3

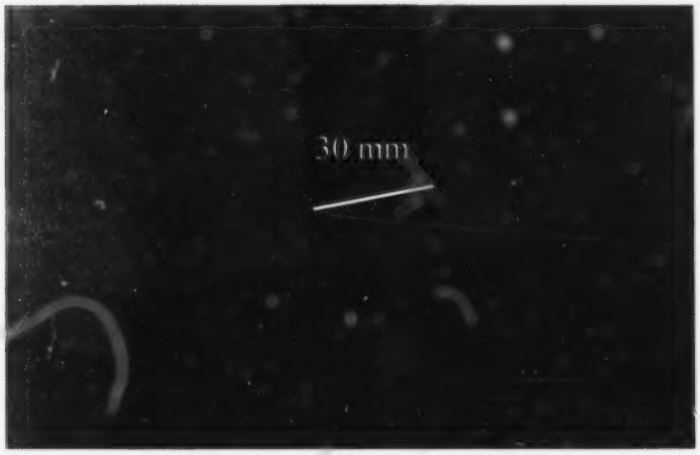
TEST: 9933.3
Date: 99/02/02 **Air Temperature:** +0.8°C
Time: 12:10 - 12:35 **Facility:** Taxiway A
Test Location: North end; west side **Length of Test Strip:** 1200 m
Surface Conditions: Loose moist (moisture content of about 5%) snow (38 to 46 mm) at –0.4°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
40	1	0.12	0.24	0.27		0.23
	2	0.12	0.24	0.27		0.23
	3	0.12	0.24	0.27		0.20
	4	0.12	0.24	0.27		0.22
	5	0.12	0.23	0.27		0.22
	6	0.12	0.23	0.26		0.18
	7	0.12	0.24	0.26		0.19
	8	0.12	0.24	0.26		0.25
	9	0.12	0.24	0.27		0.24
	10	0.12	0.24	0.27		0.22
	11	0.12	0.24	0.27		0.22
	12	0.12	0.24	0.26		0.23
	Average	0.12	0.24	0.27		0.22
80	1	0.10	0.37	0.30		0.29
	2	0.10	0.29	0.29		0.30
	3	0.10	0.26	0.28		0.30
	4	0.11	0.21	0.29		0.29
	5	0.11	0.17	0.29		0.32
	6	0.11	0.19	0.29		0.32

	7	0.11	0.18	0.29		0.31
	8	0.11	0.17	0.29		0.28
	9	0.11	0.16	0.29		
	10	0.11	0.15	0.29		
	11	0.11	0.15	0.29		
	12	0.11	0.15	0.28		
	Average	0.11	0.20	0.29		0.30
65	1	0.12	0.32	0.30		0.23
	2	0.12	0.32	0.31		0.21
	3	0.12	0.31	0.31		0.26
	4	0.12	0.31	0.32		0.25
	5	0.13	0.32	0.31		0.20
	6	0.13	0.30	0.28		0.22
	7	0.13	0.30	0.32		0.24
	8	0.12	0.31	0.31		0.27
	9	0.12	0.30	0.30		0.25
	10	0.12	0.29	0.30		0.27
	11	0.13	0.30	0.31		0.24
	12	0.12	0.30	0.31		0.25
	Average	0.12	0.31	0.31		0.24

Special Compaction Tests

Snow stopped falling at about 13:30, the sky started to clear and the wind died. The sun came out at 14:45. At the request of the author, a series of special compaction tests were conducted on a 300 m long strip of undisturbed virgin snow on the section of taxiway A between D and E. The purpose of this test series was to determine the compaction of snow caused by test tires belonging to different test vehicles and/or devices. Since the snow was uniformly thick (45 mm) and moist, and because there was no wind, it was an opportune moment to conduct these tests. The snow was very moist, about 5% in moisture content, because tight snowballs could be made, but no water could be pressed out by hand squeezing. To prevent any spreading or splashing of snow by the tires of the operating vehicles and covering the tracks left by the test tires, the tests were performed at a constant speed of 40 km/h. To prevent overlapping tracks, only three devices were used. For ease of identification of the tracks, one device was run on one half of the lane. After the measurements were completed, another device was run on the other half of the track. The third vehicle was run along the central line of the track. These tests were performed from 15:00 to 15:30 using the IMAG, the SFT and a GT with slush cutter test tires (Figure 3). Fortunately, immediately after these tests, the B757 also traversed this area while taxiing on taxiway A on its way to the main runway. This provided an opportunity to measure the compaction activities generated by the aircraft (Figure 4).

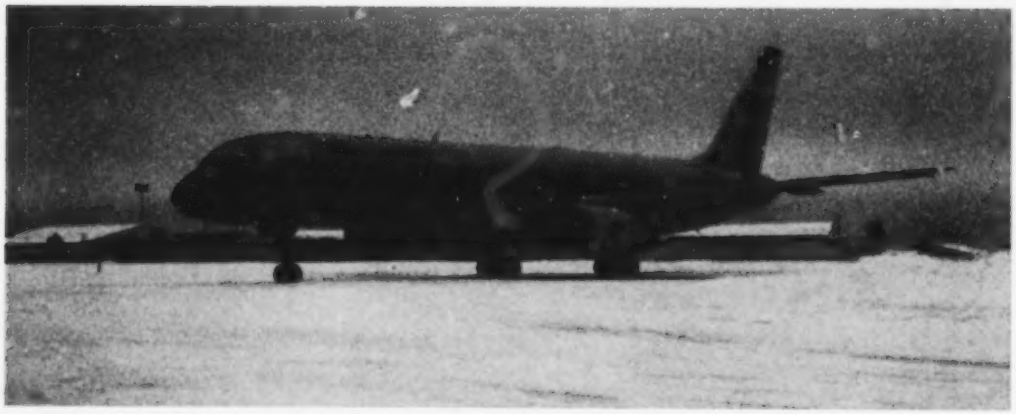


(a)

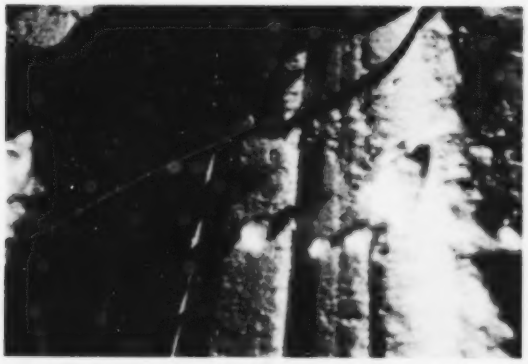
(b)

(c)

Figure 3. Tracks left on the snow by IMAG (a), SFT (b), and GT (c)



(a)



(b)

(c)

Figure 4. NASA B757 taxiing on the snowy parallel taxiway A at K.I. Sawyer Airbase, Michigan (a), track of compressed snow produced by one of the pair of tires of the left main gear (b), and the profile of compacted snow in the central section of the track (c)

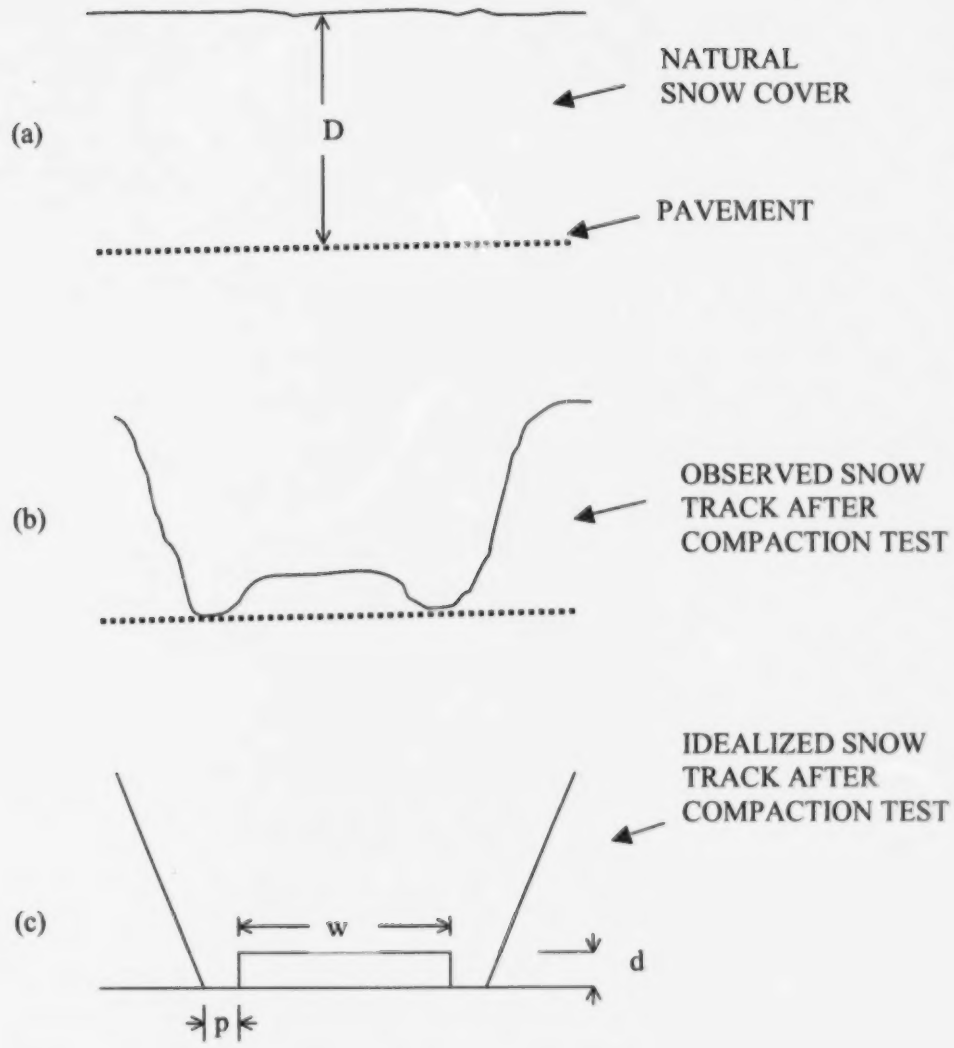


Figure 5. Characteristics of the freshly fallen loose, but moist snow cover on the pavement immediately before the compaction tests (a), observed cross section of the compacted snow of the track after the passage of a device (b), and an idealized profile of the observed snow track (c)

Figures 3 and 4 show photographs of the tracks produced by the three ground vehicles and the aircraft during the compaction tests on the snow-covered taxiway.

To evaluate the densification processes induced by the different devices, samples of compacted snow were taken with the cylindrical snow sampler from the central sections of the compacted track left by the IMAG, SFT and B757. The snow sampler could not, however, be used for the narrow track left by the GT. In this case, a full width (20 mm) rectangular section (100 mm long) of the compacted snow was removed carefully for evaluating the density.

Figure 5 illustrates the observed and the idealized characteristics of the vertical profile of the compacted snow cover immediately after the compaction tests. Table 4 provides a summary of the observations made on the profiles and characteristics of the compacted snow masses. It is interesting to note that the density of compacted snow was very similar for all the ground vehicles used in this test series. However, the IMAG tire compacted essentially all the snow under its tire at the speed (40 km/h) of the vehicles used here. The SFT removed about 25% of the snow on its sides and the GT, with its slush cutting tires, threw more than half of the snow on the sides. The aircraft compacted all the snow under the tire; therefore compaction performance of the IMAG was comparable to the performance of the aircraft tire. This is not surprising, as the IMAG used an aircraft type tire during this test.

Table 4. Details of dynamic compaction tests of 2 February 1999 at K.I. Sawyer Airbase involving three ground vehicles – IMAG, SFT and GT – and the B757 test aircraft

Device	Speed km/h	D mm	ρ_n kg.m^{-3}	ρ_c kg.m^{-3}	w mm	d mm	p mm	Undisturbed Snow Mass $wD\rho_n/1000$ g	Compacted Snow Mass $wd\rho_c/1000$ g	% Compaction
IMAG	40	43	105	617	120	7	3	5.4	5.2	96
SFT	40	43	105	671	75	5	3	3.4	2.5	74
GT	40	43	105	624	20	3	3	0.9	0.4	44
B757	10	43	105	401	224	11	0	9.9	9.7*	98

* assuming uniform compaction; neglecting the ridges of less compacted snow

Between 16:30 and 17:30, a few aircraft tests were carried out on the snow on the designated strip of runway 01-19. The strip was now covered with a thick snow cover of very non-uniform groomed snow. While trying to remove the snow from the shoulders of the test strip, the snowplough had dumped more snow on the strip itself. This was caused by the wind blowing from the west. This snow could best be described as processed snow. The thickness varied from 40 mm to 60 mm and the density was found to be significantly higher (Table 5a) than the natural snow cover that was there during the morning. Table 5b provides the results obtained by the ground vehicles immediately before the tests conducted by the aircraft. These devices used one side of the test strip on

the runway. The results obtained by the ground vehicles immediately after the aircraft tests are given in Table 5c.

Table 5a. Characteristics of groomed snow on the test strip of runway 01-19 at K.I. Sawyer Airbase during the evening of 2 February 1999 corresponding to Tests 9933.4 and 9933.5

Runway	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
01-19	16:20	40 to 60	160	-0.7	+1.6

Table 5b. Friction test results reported by the ground test vehicles on the north end of runway 01-19 during the evening of 2 February 1999 for Test 9933.4

TEST: 9933.4 Before Aircraft
Date: 99/02/02 **Air Temperature:** +1.6°C
Time: 16:20 - 16:25 **Facility:** 01-19
Test Location: Test strip on 01-19 **Length of Test Strip:** 400 m
Surface Conditions: Loose, groomed moist snow (40 mm to 60 mm) at an average temperature of –0.7°C (Top at –0.2°C, Bottom at –1.3°C)

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.01		0.32		0.36
	2	0.02		0.32		0.37
	3	0.02		0.30		0.32
	4	0.02		0.29		
	Average	0.02		0.31		0.35

Table 5c. The run matrix for the test flights on 2 February 1999 at K.I. Sawyer Airbase

Flight	Run	Time	LDG/TO Configuration	Description	Surface Condition
R093	1	16:25	LDG	60 kn tare run	Loose, groomed moist snow (40 mm to 60 mm) at an average temperature of –0.7°C (Top at –0.2°C, Bottom at –1.3°C)
R093	2		LDG	60 kn braking run	
R093	3		LDG	80 kn tare run	
R093	5	17:55	LDG	80 kn braking run	

Table 5d. Test results reported by the ground test vehicles on the north end of 01-19 immediately after the aircraft tests during the evening of 2 February 1999 for Test 9933.5

TEST: 9933.5 After Aircraft

Date: 99/02/02 **Air Temperature:** +1°C
Time: 17:55 - 18:00 **Facility:** 01-19
Test Location: Test strip on 01-19 **Length of Test Strip:** 400 m
Surface Conditions: Loose, groomed moist snow (40 mm to 60 mm) at an average temperature of –0.7°C (Top at –0.2°C, Bottom at –1.3°C)

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.06		0.32		0.36
	2	0.04		0.33		0.25
	3	0.06		0.32		0.35
	4	0.06		0.34		0.29
	Average	0.06		0.33		0.31

3.3 Wednesday 3 February 1999

The sky was relatively clear during most of the night. This allowed the air temperature to drop. A patchy cloud cover moved in from the southwest during the morning. The local weather conditions at Marquette at 07:00 were as follows:

T_A = –4.5°C, Wind = SW 5 km/h, Visibility = 15 km. Ceiling = unlimited,
Relative Humidity = 81%

At K.I. Sawyer Airbase, the weather conditions were very similar to those of Marquette. An examination of the groomed snow on runway 01-19 was made at about 07:50 when the sun was just coming out of the cloud patches. The snow strip on the runway was groomed, but the surface was rather rough. It was decided to carry out a detailed examination of this snow strip after the morning's ground vehicle tests.

From 08:35 to 09:10, vehicular tests were carried out on a narrow (about 1 m in width) strip on the east bank of the runway not far from the main snow strip. During this test period the average air temperature was –3.4°C. The details of these test results are given in Table 6.

The site used for these tests (9934.1) consisted of a mixed bag of winter contaminants: bubbly white ice, compacted snow and loose, but processed snow. A good part of the icy section was frozen on top of an old strip of white paint beside the runway. It must have formed by the solidification of partially melted snow, forming a melt-freeze zone of granular ice on the painted strip. At the end of the tests, small sections of compacted snow and ice were removed from the white painted strip. The cohesive force between the ice and the compacted snow and the painted strip was obviously low.

Table 6. Test results reported by the ground test vehicles on the east bank of the aircraft test strip on runway 01-19 during the morning of 3 February 1999 for Test 9934.1

TEST: 9934.1
Date: 99/02/03
Time: 08:35 - 09:10
Test Location: East bank of runway 01-19 near aircraft test strip
Air Temperature: 3.8°C at 08:20 to 3.0°C at 09:15
Facility: 01-19
Length of Test Strip: 1000 m
Surface Conditions: Mixed: compacted and processed snow, granular ice

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
40	1	0.25	0.32	0.36		0.25
	2	0.27	0.31	0.38		0.27
	3	0.27	0.30	0.38		0.29
	4	0.27	0.30	0.36		0.32
	5	0.27	0.31	0.36		0.29
	6	0.28	0.30	0.34		0.29
	7	0.27	0.32	0.37		0.32
	8	0.27	0.33	0.39		
	9	0.28	0.34	0.37		
	10	0.30	0.37	0.40		0.35
	Average	0.27	0.32	0.37		0.30
65	1	0.25	0.29	0.32		
	2	0.26	0.31	0.35		0.31
50	3	0.27	0.32	0.37		0.33
for ERD	4	0.27	0.30	0.36		0.31
	5	0.27	0.28	0.36		0.29
	6	0.28	0.30	0.33		0.27
	7	0.28	0.32	0.34		0.30
	8	0.28	0.34	0.37		0.27
	9	0.30	0.36	0.40		0.25
	10	0.29	0.39	0.39		
	Average	0.28	0.32	0.36		0.29
90	1	0.25	0.31	0.34		0.24
	2	0.27	0.31	0.34		0.27
50	3	0.28	0.31	0.34		0.31
for ERD	4	0.26	0.32	0.35		0.28
	5	0.26	0.32	0.35		0.29
	6	0.26	0.34	0.31		0.22
	7	0.29	0.33	0.36		

	8	0.29	0.33	0.36		0.36
	9	0.33	0.38	0.41		0.31
	10	0.32	0.36	0.38		
	Average	0.28	0.33	0.35		0.29

TEST: 9934.1 (Cont'd)

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
40	1	0.26	0.31	0.35		0.20
	2	0.25	0.30	0.33		0.29
	3	0.25	0.28	0.35		0.29
	4	0.26	0.28	0.35		0.27
	5	0.24	0.29	0.34		0.25
	6	0.25	0.30	0.33		0.27
	7	0.26	0.30	0.36		0.22
	8	0.28	0.30	0.38		0.25
	9	0.33	0.32	0.40		0.25
	10	0.32	0.34	0.40		0.30
	Average	0.27	0.30	0.36		0.26
65 50 for ERD	1	0.24	0.30	0.36		0.24
	2	0.25	0.30	0.34		0.25
	3	0.26	0.30	0.32		0.31
	4	0.25	0.30	0.35		0.26
	5	0.26	0.30	0.36		0.27
	6	0.26	0.33	0.35		0.28
	7	0.25	0.34	0.35		0.22
	8	0.31	0.36	0.37		0.28
	9	0.29	0.36	0.38		0.35
	10	0.30	0.36	0.38		0.24
	Average	0.27	0.33	0.36		0.27
90 40 for ERD	1	0.24	0.32	0.34		0.20
	2	0.25	0.30	0.36		0.28
	3	0.25	0.32	0.35		0.23
	4	0.25	0.31	0.37		0.28
	5	0.26	0.30	0.36		0.27
	6	0.24	0.32	0.36		0.28
	7	0.24	0.35	0.32		
	8	0.28	0.34	0.38		0.28
	9	0.34	0.39	0.39		0.24
	10	0.36	0.37	0.39		0.29
	Average	0.27	0.33	0.36		0.26

After the completion of the vehicular tests on the east bank of the runway, a series of measurements was carried out on the snow strip on the runway designated for aircraft tests. The test section was prepared by grooming previous day's snow using a snowplough and a front loader. One snow sample for density was taken from the north end of the test section and one sample was taken from the south end (Table 7). One set of snow thickness measurements was also carried out across the width of the snow strip, near the middle of the strip, to obtain a thickness profile. For this, thickness was measured 1 m apart across the 15 m wide test section. The following snow profile shows that the snow cover in the test section was far from uniform and varied from 17 mm to 40 mm.

Horizontal thickness (in mm) profile, 1 m apart, from west to east was:
35, 38, 36, 40, 22, 35, 24, 25, 35, 28, 17, 33, 32, 36

Table 7. Characteristics of groomed, aircraft snow strip on runway 01-19 at K.I. Sawyer Airbase during the morning of 3 February 1999

Runway 01-19	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
North end	09:30	46	506	–4.8	–3.0
South end	09:50	18	538	–4.6	–2.6
			Average: 522		

Because of a scheduled tour of the aircraft for school children and people from the local community, all morning tests using the aircraft were cancelled. As the morning progressed, the wind started to pick up and a heavy cloud cover moved in. At about 10:30, the sun disappeared for the day.

A series of tests was carried out in the afternoon from 13:20 to 14:00 on the west side of parallel taxiway A, between the short taxiways D and E, but closer to D. This section of taxiway A was covered with a layer of day-old compacted and aged snow. The density of this material was found to be 650 $kg.m^{-3}$. This sintered layer had been produced during the previous day when the freshly fallen moist snow was compacted by the movement of vehicular traffic during the entire day. In addition to the processes of mechanical compaction, the snow mass on this section had also been strengthened by the processes of aging or sintering at an overnight temperature of about –5°C. A large number of tests were carried out on this strip as can be seen in Table 8 (note the non-sequential number for these tests caused by the cancellation of the aircraft tests in the morning). The snow cover was strong enough to withstand all the tribological processes during the tests without incurring any visible damages, even though the temperature of the compacted snow mass was relatively high at –0.8°C. It should be mentioned here that the air temperature was +2.2°C and it was snowing during the tests. It was also very windy, with wind coming from the south almost parallel to the length of the taxiway. Consequently,

there was a thin layer of loose, but moist snow on the surface of the compacted snow on the pavement.

Table 8. Test results reported by the ground vehicles for tests on the compacted and aged snow on the west side of taxiway A during the afternoon of 3 February 1999 for Test 9934.4

TEST: 9934.4
Date: 99/02/03 **Air Temperature:** +2.2°C
Time: 13:20 - 14:00 **Facility:** Taxiway A
Test Location: West side of taxiway A, between D & E **Length of Test Strip:** 1000 m
Surface Conditions: Compacted snow (density of 650 $kg.m^{-3}$) at –0.8°C with a thin layer of blowing moist snow on the surface

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (135 psi)	ERD
40	1	0.23	0.24	0.29		
	2	0.20	0.23	0.27		0.23
	3	0.23	0.26	0.29		0.24
	4	0.23	0.28	0.29		0.28
	5	0.23	0.26	0.28		0.29
	6	0.23	0.27	0.30		0.26
	7	0.22	0.26	0.31		0.27
	8	0.23	0.27	0.30		0.24
	9	0.23	0.27	0.28		0.27
	10	0.22	0.28	0.28		0.22
	Average	0.23	0.26	0.29		0.26
50	1	0.21	0.26	0.28	0.22	0.26
	2	0.19	0.25	0.26	0.22	0.30
	3	0.21	0.26	0.25	0.22	0.26
	4	0.22	0.28	0.27		0.26
	5	0.22	0.27	0.28		0.23
	6	0.21	0.27	0.29		0.33
	7	0.22	0.26	0.30		0.25
	8	0.23	0.25	0.28		0.27
	9	0.21	0.26	0.27		0.23
	10	0.23	0.27	0.27		0.22
	Average	0.22	0.26	0.28	0.22	0.26
65	1	0.21	0.26	0.28		0.27
	2	0.18	0.25	0.27		0.24
	3	0.21	0.27	0.28		0.30

	4	0.24	0.28	0.28		0.24
	5	0.22	0.28	0.26		0.27
	6	0.21	0.27	0.27		0.29
	7	0.21	0.27	0.29		0.26
	8	0.20	0.27	0.27		0.18
	9	0.18	0.28	0.27		
	10	0.22	0.29	0.25		
	Average	0.21	0.27	0.27		0.26

TEST: 9934.4 (Cont'd)

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
40	1	0.19	0.25	0.28		0.21
	2	0.20	0.25	0.27		0.30
	3	0.22	0.26	0.24		0.26
	4	0.20	0.27	0.22		0.27
	5	0.22	0.26	0.26		0.24
	6	0.22	0.25	0.28		0.22
	7	0.21	0.28	0.29		0.27
	8	0.18	0.25	0.26		0.20
	9	0.18	0.26	0.26		0.21
	10	0.19	0.27	0.25		0.26
	Average	0.20	0.26	0.26		0.24
50	1	0.19	0.27	0.25	0.22	0.26
	2	0.16	0.26	0.25	0.22	0.30
	3	0.19	0.26	0.28	0.22	0.27
	4	0.19	0.28	0.27		0.20
	5	0.21	0.26	0.25		0.25
	6	0.19	0.26	0.29		0.27
	7	0.20	0.27	0.29		0.23
	8	0.18	0.28	0.23		0.26
	9	0.17	0.28	0.24		0.25
	10	0.19	0.26	0.25		0.22
	Average	0.19	0.27	0.26	0.22	0.25

The B757 experimental systems preflight was initiated at approximately 13:00 and the aircraft came out of the hanger at 13:35, but the low ceiling and the blowing snow prevented the aircraft from conducting any tests for a long time. Run 1, the only run of the day, was finally conducted at 15:01. It was a 60 kn tare run and it was conducted following ground test vehicle passes through the test section. Ground vehicles performed

the tests on one side of the groomed snow strip from 14:45 to 14:50. These were termed as tests before aircraft and the results are shown in Table 9a. Aircraft testing was terminated after the first run due to low ceilings, poor visibility and continued precipitation of snow. Shortly after the aircraft tests were terminated, the ground vehicles performed another series of tests on the test section from 16:10 to 16:45 (Table 9b).

Post-test examinations of the snow in the test section were carried out after 17:00 when all the ground vehicles had completed their tests and it was safe to spend some time on the runway. Snow-density samples of undisturbed groomed snow, very close to a track left by the aircraft, were taken along with a sample from the central part of a 222 mm wide track of compacted snow made by the tires of the main gear of the B757.

The density of undisturbed snow was found to be 411 $kg.m^{-3}$. This was measurably lower than the density of runway test section snow ascertained in the morning and given in Table 7. This rarified state of snow was caused by the precipitation of new snow on the test section during the afternoon. Table 9c shows that the aircraft tires seemed to have increased the density of snow by about 44% from 411 $kg.m^{-3}$ to 591 $kg.m^{-3}$. Compare this with the densification ratio seen earlier during the previous day's tests (Table 4). A densification ratio of 382% was observed when the snow was compacted to a density of 401 $kg.m^{-3}$ from 105 $kg.m^{-3}$.

Table 9a. Results of ground vehicle tests on the test section of the runway before the aircraft test in the afternoon of 3 February 1999

TEST: 9934.2 Before Aircraft

Date: 99/02/03 **Air Temperature:** +0.8°C
Time: 14:45 - 14:50 **Facility:** 01-19
Test Location: Test strip on runway **Length of Test Strip:** 400 m
Surface Conditions: Groomed and lightly compacted snow (17 mm to 40 mm) covered by a thin layer of new moist snow at –0.9°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.12		0.34		0.42
	2	0.08		0.33		0.37
	3	0.04		0.32		0.41
	4	0.07		0.31		0.36
	Average	0.08		0.33		0.39

Table 9b. The run matrix for the test flight on 3 February 1999 at K.I. Sawyer Airbase

Flight	Run	Time	LDG/TO/RTO Configuration	Description	Surface Condition
R094	1	16:40	LDG	60 kn tare run	Non-uniform lightly compacted groomed snow with a cover of fresh snow at – 0.7°C, depth varying from 17 mm to 50 mm, blowing light snow with wind parallel to the runway from south (facing the aircraft)

Table 9c. Results of ground vehicle tests on the test section of the runway after the aircraft test on 3 February 1999

TEST: 9934.3 After Aircraft

Date: 99/02/03 **Air Temperature:** +1.0°C
Time: 16:45 **Facility:** 01-19
Test Location: Test strip on runway **Length of Test Strip:** 400 m
Surface Conditions: Groomed and lightly compacted snow (17 mm to 40 mm) with a thin layer of new moist snow at –0.7°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.19		0.36		0.29
	2	0.14		0.33		0.32
	3	0.15		0.32		
	4	0.16		0.33		
	Average	0.16		0.34		0.31

Table 9d. Compaction of groomed snow on the test strip of runway 01-19 by B757 aircraft's main gear tires during a 60 kn tare run (Run 1) of Runway Friction Flight #3 at 13:00 on 3 February 1999

Runway	Time	Snow Temperature °C	Undisturbed Snow Density $kg.mm^{-3}$	B757 Compacted Snow Density $kg.mm^{-3}$	Compaction Ratio %
01-19	17:15	-0.7	411	591	43.8

3.4 Thursday 4 February 1999

Snow flurry activities continued through the night and into this morning, but the air temperature dropped and the wind picked up. The direction of the wind changed from the prevalent direction of southwest to northwest during the morning. The local weather conditions at Marquette at 06:00 were as follows:

T_A = –5.5°C, Wind = NW 26 km/h, Visibility = 10 km, Ceiling = 168 m,
Relative Humidity = 74%, Light Snow

At K.I. Sawyer Airbase, the air temperature was –11°C. This was significantly colder than –5.5°C reported for Marquette. A total of about 25 mm of snow had accumulated on the ground surfaces of the airbase during the past 15 hours. Almost continuous precipitation of solids together with the gusty wind conditions resulted in huge drifts on the runway surfaces and various movement areas on taxiways. Consequently, undesirable test conditions were prevalent throughout the airbase. During the morning briefing sessions, it was decided to remove all loose and drifted snow from both the runway test section and the test site used the previous day on the west side of taxiway A. During this meeting, NASA also requested that all participants from Canada, France, Norway and Sweden extend their stay until Monday 9 February. A separate meeting was then convened among the participants from these countries and a unanimous decision was made to go along with NASA's proposal. While these meetings were going on, Mother Nature decided to clear the sky and let the sun come out and shine brightly. However, the northwest crosswind persisted during the morning and that was detrimental to any aircraft testing.

The first ground vehicular tests of the morning were conducted from 10:15 to 11:00, with the ground vehicles on a 500 m long test section on the west bank of the southern end of taxiway A. All loose snow was removed from this section, as planned, before conducting the tests. All five devices or tribometers took part in this test series. These tests were essentially a repetition of the previous day's tests, but the compacted contaminant layer in this test section had had a chance to strengthen further due to aging for a longer duration. Moreover, the temperature of this layer had also dropped from the previous day's test temperature of –0.8°C to this morning's temperature of –7.2°C. The average density was found to be 598 $kg.m^{-3}$, which was, however, slightly less than that (650 $kg.m^{-3}$) of the material tested the previous day.

Table 10a. Characteristics of compacted and aged snow on taxiway A during the morning ground vehicular tests of 4 February 1999, corresponding to Test 9935.1

Taxiway A West Bank	Time	Snow Depth mm	Snow Density kg.mm^{-3}	Snow Temperature °C	Air Temperature °C
North end	10:25	11	555	-9.0	-11.0
South end	11:10	12	640	-8.7	-10.5
			Average: 598		

Table 10b. Results of ground vehicle tests on the test section off the south end of taxiway A during the morning of 4 February 1999

TEST: 9935.1
Date: 99/02/04 **Air Temperature:** –11°C
Time: 10:15 - 11:00 **Facility:** Taxiway A
Test Location: West bank of taxiway A, **Length of Test Strip:** 500 m south end
Surface Conditions: Compacted snow (12 mm thick) of average density of 598 kg/m^3 at –8.8°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65	1	0.22	0.25	0.31	0.16	0.24
	2	0.20	0.23	0.35	0.16	0.24
	3	0.19	0.25	0.27	0.16	0.22
	4	0.17	0.26	0.28	0.16	0.17
	5	0.20	0.22	0.30	0.16	
	Average	0.20	0.24	0.30	0.16	0.22
65	1	0.16	0.26	0.26	0.20	0.16
	2	0.18	0.25	0.29	0.18	0.20
	3	0.17	0.24	0.28	0.16	0.18
	4	0.24	0.25	0.26	0.14	0.21
	5	0.19	0.27	0.34	0.13	
	Average	0.19	0.25	0.29	0.16	0.19
50	1	0.24	0.25	0.28	0.22	0.15
	2	0.22	0.25	0.22	0.22	0.19
	3	0.19	0.24	0.22	0.22	0.21
	4	0.18	0.25	0.23	0.20	0.15
	5	0.19	0.27	0.24	0.20	
	Average	0.20	0.25	0.24	0.21	0.18

50	1	0.20	0.28	0.24		0.17
	2	0.21	0.25	0.26		0.19
	3	0.23	0.24	0.26		0.16
	4	0.21	0.23	0.27		0.18
	5	0.22	0.26	0.30		
	Average	0.21	0.25	0.27		0.18
40	1	0.14	0.27	0.32		
	2	0.16	0.26	0.29		
	3	0.20	0.27	0.22		
	4	0.17	0.22	0.24		
	5	0.18	0.24	0.26		
	Average	0.17	0.25	0.27		
40	1	0.16	0.22	0.24		
	2	0.18	0.23	0.29		0.17
	3	0.20	0.25	0.31		0.18
	4	0.20	0.24	0.25		0.21
	5	0.19	0.25	0.33		
	Average	0.19	0.24	0.28		0.19

TEST: 9935.1 (Cont'd)

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65	1	0.16	0.24	0.25		0.15
	2	0.13	0.25	0.23		0.19
	3	0.15	0.24	0.21		0.19
	4	0.20	0.25	0.27		0.13
	5	0.18	0.25	0.26		
	Average	0.16	0.25	0.24		0.17
65	1	0.17	0.20	0.23		0.15
	2	0.23	0.20	0.23		0.21
	3	0.24	0.21	0.22		0.18
	4	0.19	0.20	0.26		0.22
	5	0.19	0.23	0.26		
	Average	0.20	0.21	0.24		0.19
50	1	0.20	0.27	0.31		0.13
	2	0.21	0.26	0.27		0.16
	3	0.17	0.23	0.24		0.14
	4	0.20	0.23	0.21		0.13
	5	0.22	0.21	0.21		
	Average	0.20	0.24	0.25		0.14
50	1	0.22	0.28	0.24		0.15

	2	0.21	0.26	0.22		0.16
	3	0.22	0.29	0.25		0.14
	4	0.19	0.21	0.25		0.14
	5	0.22	0.25	0.32		
	Average	0.21	0.26	0.26		0.15
40	1	0.15	0.30	0.20		
	2	0.15	0.28	0.21		0.14
	3	0.16	0.27	0.22		0.17
	4	0.15	0.26	0.28		0.14
	5	0.18	0.30	0.25		
	Average	0.16	0.28	0.23		0.15
40	1	0.16	0.28	0.26		0.14
	2	0.19	0.26	0.25		0.18
	3	0.19	0.24	0.22		0.16
	4	0.19	0.28	0.23		0.13
	5	0.24	0.30	0.29		
	Average	0.19	0.27	0.25		0.15

At the end of the morning tests, it was noticed that there were a number of strips of absolutely bare pavement in certain sections along the length of the test strip. These strips were in pairs and parallel to each other. The distance between these lines suggested that they were created by the two sets of tires of the Blazer that carried out the ERD measurements. The compacted snow-ice layer was fractured and small sections had been removed completely from the pavement by the braking actions, with locked tires, of this vehicle. Examinations revealed that the snow was debonded from the underlying pavement because of a thin dusting of sand in the interface between these two layers. The snow was well consolidated and could be removed easily from the pavement by a prying action with a spatula. The material was very uniform and consisted of fine equiaxed grains with diameters less than 1 mm.

Vehicular tests resumed again in the afternoon at about 14:20. The test site selected was on the east bank near the south end of taxiway A. It was a short strip, only 200 m in length. Here again, the snow had been compacted during previous days by the mechanical actions of surface vehicles going back and forth on the snow cover of the test section. The characteristics of the snow cover were determined immediately before the vehicular tests began (Table 11a). During the tests, the sun was shining brightly, but it was still very windy.

Table 11a. Characteristics of the 200 m long, compacted and aged snow on the east bank of taxiway A during the afternoon of 4 February 1999, corresponding to Test 9935.2

Taxiway A East Bank	Time	Snow Depth mm	Snow Density kg.mm^{-3}	Snow Temperature °C	Air Temperature °C
North end	14:20	12	510	-7.8	-9.2
South end	14:35	13	673	-8.9	-9.7
			Average: 592		

Table 11b. Results of ground vehicle tests on the test section on the east bank of the south end of taxiway A during the afternoon of 4 February 1999

TEST: 9935.2

Date: 99/02/04 **Air Temperature:** –9.5°C

Time: 14:40 - 15:35 **Facility:** Taxiway A

Test Location: East bank of taxiway A, south end **Length of Test Strip:** 200 m

Surface Conditions: Compacted and aged snow of average density of 592 kg.m^{-3} at –8.4°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65	1	0.19	0.24	0.30	0.29	0.23
	2	0.20	0.24	0.33	0.22	0.24
	Average	0.20	0.24	0.32	0.26	0.24
65	1	0.22	0.29	0.29	0.31	0.21
	2	0.23	0.29	0.29	0.31	0.20
	Average	0.23	0.29	0.29	0.31	0.21
50	1	0.20	0.26	0.27	0.22	0.18
	2	0.21	0.25	0.28	0.18	
	Average	0.21	0.26	0.28	0.20	0.18
50	1	0.19	0.23	0.25	0.29	0.15
	2	0.19	0.26	0.28	0.20	0.13
	Average	0.19	0.25	0.27	0.25	0.14
40	1	0.20	0.22	0.26	0.31	0.14
	2	0.20	0.23	0.26	0.22	0.16
	Average	0.20	0.23	0.26	0.27	0.15
40	1	0.19	0.25	0.28	0.18	0.16
	2	0.19	0.24	0.27	0.22	0.16
	Average	0.19	0.25	0.28	0.20	0.16

65	1	0.18	0.25	0.26	0.33	
	2	0.19	0.22	0.28	0.27	0.16
	Average	0.19	0.24	0.27	0.30	0.16
65	1	0.20	0.25	0.24	0.20	
	2	0.21	0.23	0.27	0.29	
	Average	0.21	0.24	0.26	0.25	
50	1	0.18	0.25	0.25	0.29	
	2	0.18	0.25	0.25	0.29	
	Average	0.18	0.25	0.25	0.29	
50	1	0.15	0.23	0.23	0.27	
	2	0.20	0.23	0.22	0.31	
	Average	0.18	0.23	0.23	0.29	
40	1	0.19	0.23	0.24	0.24	
	2	0.17	0.24	0.23	0.24	0.13
	Average	0.18	0.24	0.24	0.24	0.13
40	1	0.19	0.25	0.23	0.22	0.13
	2	0.16	0.22	0.22	0.20	0.13
	Average	0.18	0.24	0.23	0.21	0.13

The wind speed decreased significantly during the later part of the afternoon to about 9 km/h with gusts up to 14 km/h. Except for some traces of thin clouds, the sky was blue and the sun was shining brightly in the western sky. It was an ideal afternoon for aircraft testing and NASA's B757 crew could conduct some tests without breaking any rules.

Immediately before the aircraft tests, the test section was examined and a sample was recovered to determine the density. The ground vehicles performed one set of friction measurements, between 15:45 and 15:50, on one side of the test section on runway 01-19. The results are given in Table 12a. The test strip consisted of loosely compacted snow left after the previous day's tests. The material was dense with a density of 414 $kg.m^{-3}$, but not bonded well. An effort was made to remove most of the loose, newly deposited snow on the surface by using an air blower. In all, the aircraft completed five runs from 16:00 to 17:30. It was getting dark and the visibility decreased significantly. The aircraft testing was terminated because of darkness. The post-aircraft ground vehicle tests, reported in Table 12b, were performed as soon as the aircraft departed from the test region.

Table 12a. Results of ground vehicle tests on the test section of runway 01-19 before the aircraft tests in the afternoon of 4 February 1999

TEST: 9935.4 Before Aircraft

Date: 99/02/04 **Air Temperature:** –9.7°C
Time: 15:45 - 15:50 **Facility:** 01-19
Test Location: Designated aircraft test section **Length of Test Strip:** 400 m
Surface Conditions: Semi-compacted to loose groomed snow (22 to 50 mm), density of 414 kg.m^{-3} at –8.9°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.10		0.37		0.35
	2	0.10		0.39		
	3	0.17		0.37		0.31
	4	0.17		0.35		0.38
	Average	0.14		0.37		0.35

Table 12b. The run matrix for the test flights on Thursday 4 February 1999 at K.I. Sawyer Airbase on groomed aged snow cover

Flight	Run	Time	LDG/TO Configuration	Description	Surface Condition
R095	1	15:50	LDG	60 kn tare run	Non-uniform semi compacted groomed and overnight aged snow at –8.9°C (start) to –11.0°C (end) with thickness varying from 20 mm to 50 mm
R095	2		LDG	60 kn braking run	
R095	3		LDG	100 kn tare run	
R095	5	▼	LDG	100 kn braking run	
R095	8	17.30	LDG	80 kn braking run	

Table 12c. Results of ground vehicle tests on the test section of runway 01-19 immediately after the aircraft tests in the evening of 4 February 1999

TEST: 9935.5 After Aircraft

Date: 99/02/04 **Air Temperature:** –11.7°C
Time: 17:30 - 17:35 **Facility:** 01-19
Test Location: Designated aircraft test section **Length of Test Strip:** 400 m
Surface Conditions: Semi-compacted to loose groomed snow (22 mm to 50 mm), density of 414 kg.m^{-3} at –11.0°C, pavement below snow at –6.7°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.17		0.31		0.36
	2	0.17		0.28		0.39
	3	0.16		0.34		
	4	0.15		0.35		0.32
	Average	0.16		0.32		0.36

3.5 Friday 5 February 1999

The air temperature remained almost unchanged during the evening and night of Thursday 4 February. However, a cloud cover moved in during the morning hours of Friday 5 February and the wind speed picked up. The direction of the wind changed toward the prevalent direction of southwest during the morning. The local weather conditions at Marquette at 06:00 were as follows:

T_A = –10.5°C, Wind = SW 20 km/h, Visibility = 10 km, Ceiling = 200 m,
Relative Humidity = 54%.

At K.I. Sawyer Airbase, the air temperature was 7.1°C at 09:40, which was slightly warmer than that reported for Marquette. Because of the heavy overcast, low ceiling and high wind speed, all tests with aircraft were cancelled. It was then decided to conduct some ground vehicular tests on a strip of compacted snow with and without any applications of sand. These tests were performed on a 300 m long section on the east bank of taxiway A not far from the north end. The west half of the test section (called A) was not sanded in order to obtain the base data on compacted snow. The east half of the strip (called B) was covered with an application of sand. The sand application on the test section was, however, not uniform. The vehicles made loops on the test track by going south on the west half of the track and returning on the sanded east half of the track. This way, they tried to avoid any contamination of the west half with sand carried by the test vehicles. However, the wind picked up the sand particles from the sanded section and

spread them to some extent across the centre line on the other half of the strip. The observations on snow are given in Table 13a; the results from the ground vehicle tests are given in Table 13b.

Table 13a. Characteristics of the 300 m long, compacted and aged snow on the east bank of taxiway A during the morning tests of 5 February 1999

Taxiway A East Bank	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
North end	09:40	7	528	-7.4	-7.1
South end	10:00	9	473	-7.5	-7.1
			Average: 500		
North end	11:10			-5.4	-4.8
South end	11.20			-5.5	-4.2

Table 13b. Results of ground vehicle tests on the test section of taxiway A in the morning of 5 February 1999

Test: 9936.1
Date: 99/02/05
Time: 10:40 - 11:10
Test Location: East bank of taxiway A, north end
Air Temperature: –6°C
Facility: Taxiway A
Length of Test Strip: 300 m
Surface Conditions: Compacted snow (A) and compacted snow with sand (B); average snow density of 500 $kg.mm^{-3}$

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65 Section A	1	0.17		0.28	0.22	0.26
	2	0.18		0.32	0.22	0.23
	3	0.19		0.31	0.22	0.23
	Average	0.18		0.30	0.22	0.24
65 Section B	1	0.28		0.36	0.33	0.32
	2	0.30		0.37	0.33	0.29
	3	0.27		0.41	0.33	0.27
	Average	0.28		0.38	0.33	0.29
50 Section A	1	0.19		0.20	0.22	0.19
	2	0.17		0.25	0.22	0.19

	3	0.17		0.26	0.22	0.23
	Average	0.18		0.24	0.22	0.20
50 Section B	1	0.26		0.38	0.38	0.33
	2	0.26		0.31	0.38	0.38
	3	0.29		0.35	0.38	0.27
	Average	0.27		0.35	0.38	0.33
40 Section A	1	0.18		0.33	0.33	0.22
	2	0.18		0.33	0.33	0.18
	3	0.21		0.27	0.33	0.23
	Average	0.19		0.31	0.33	0.21
40 Section B	1	0.27		0.42	0.33	0.31
	2	0.25		0.41	0.33	0.25
	3	0.31		0.42	0.33	0.25
	Average	0.28		0.42	0.33	0.27

3.6 Saturday 6 February 1999

During the early morning inspection, it was noticed that the entire runway was covered with a uniform layer of freshly fallen snow. The thickness of the snow cover was 18 mm. Due to the heavy overcast, low ceiling and high crosswind, all planned aircraft tests were cancelled. During the morning briefing hour, the flight crew decided to remove all snow from the entire runway except the 457 m (1500 ft.) long aircraft test section in the usual designated location near the north of the runway. The process of removal of the loose and dry snow with a snowblower, however, ruined the test section. While cleaning the north side of the runway, the operator of the snowblower inadvertently blew all the material from that part of the runway over the test track. The northwest crosswind also helped him. Consequently, the entire test section was very non-uniform. To achieve a uniform layer of snow cover, the material was then groomed with a front loader. This process left a very undesirable snow cover on the test section. The thickness varied from 0 to 70 mm across the 15 m wide test strip. It was also very lumpy. Some of the lumps were as big as 50 mm in diameter. The characteristics of the snow cover are given in Table 14a.

Three vehicles, the SFT, IMAG and ERD, conducted the pre-aircraft tests on one side of the processed and groomed test section of runway at 10:30 and the results are given in Table 14b. The aircraft performed a series of tests from 10:30 to 11:45 (Table 14c). The air temperature increased to –1.8°C at the end of the aircraft tests. Four ground vehicles then performed their tests on the test section (Table 14d).

Table 14a. Characteristics of the 457 m (1500 ft.) long processed and groomed snow cover on runway 01-19 corresponding to the morning B757 tests of 6 February 1999

Aircraft Test Section	Time	Snow Depth mm	Snow Density $kg.mm^{-3}$	Snow Temperature °C	Air Temperature °C
North end	09:30	0-70	375	-3.8	-2.5
South end	09:50	0-70	351	-3.8	-2.5
			Average: 363		

Table 14b. Results of ground vehicle tests on the processed and groomed snow on the aircraft test section of runway 01-19 in the morning of 6 February 1999

TEST: 9937.1 Before Aircraft

Date: 99/02/06 **Air Temperature:** -3°C
Time: 10:30 - 10:35 **Facility:** 01-19
Test Location: Aircraft test section **Length of Test Strip:** 457 m
Surface Conditions: Groomed snow (0 to 70 mm), average density = 363 $kg.m^{-3}$

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.01		0.29		0.30
	2	0.01		0.29		0.26
	3	0.01		0.29		0.33
	4	0.01		0.29		0.30
	Average	0.01		0.29		0.30

Table 14c. The run matrix for the test flights on Saturday 6 February 1999 at K.I. Sawyer Airbase on groomed moist (< 3%) loose snow cover

Flight	Run	Time	LDG/TO Configuration	Description	Surface Condition
R096A	1A	10:30	LDG	80 kn tare run	Loose moist snow, 20 to 25 mm
R096A	2A		LDG	60 kn braking run	
R096A	3A		LDG	80 kn braking run	
R096A	5A	11:45	LDG	Max. speed braking run	

Table 14d. Results of ground vehicle tests after the aircraft tests on the test section of runway 01-19 in the morning of 6 February 1999

TEST: 9937.2 After Aircraft

Date: 99/02/06 **Air Temperature:** –1.8°C
Time: 12:00 - 12:15 **Facility:** 01-19
Test Location: Aircraft test section **Length of Test Strip:** 400 m
Surface Conditions: Groomed snow (0 to 70 mm), average depth = 20 mm, average density = 357 kg.m^{-3}
Density of snow compacted by aircraft tire = 0.690 kg.m^{-3}

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.18		0.29	0.24	0.29
	2	0.17		0.30	0.24	
	3	0.16		0.21	0.24	0.27
	4	0.16		0.28		0.33
	Average	0.17		0.27	0.24	0.30

Table 15a. Results of ground vehicle tests before the aircraft tests on the test section of runway 01-19 in the afternoon of 6 February 1999

TEST: 9937.3 Before Aircraft

Date: 99/02/06 **Air Temperature:** –2.1°C
Time: 15:00 - 15:10 **Facility:** 01-19
Test Location: Between taxiway B and C **Length of Test Strip:** 400 m
Surface Conditions: Compacted snow at –3.5°C with loose, moisture content less than about 3%

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.13				0.33
	2	0.08				0.31
	3	0.12				
	4	0.13				0.22
	Average	0.12				0.29

Table 15b. The run matrix for the test flights on Saturday 6 February 1999 at K.I. Sawyer Airbase on groomed moist (< 3%) loose snow cover

Flight	Run	Time	LDG/TO Configuration	Description	Surface Condition
R096B	1B	15:10	LDG	80 kn tare run	Dry mechanically compacted snow, 12 mm
R096B	2B		LDG	60 kn braking run	
R096B	3B		LDG	80 kn braking run	
R096B	5B		LDG	Max. speed braking run	
R096B	8B	16.50	LDG	110 kn tare run	

Table 15c. Results of ground vehicle tests after the aircraft tests on the test section of runway 01-19 in the afternoon of 6 February 1999

TEST: 9937.4 After Aircraft

Date: 99/02/06 **Air Temperature:** –4.1°C
Time: 16:50 - 17:00 **Facility:** 01-19
Test Location: Between taxiway B and C **Length of Test Strip:** 400 m
Surface Conditions: Compacted snow at –4.2°C and density of 752 kg.m^{-3}

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.17			0.24	0.30
	2	0.14			0.24	0.34
	3	0.18			0.24	0.34
	4	0.18				0.32
	Average	0.17			0.24	0.33

3.7 Sunday 7 February 1999

At 06:00, it was a cool (–6.7°C) cloudy morning at Marquette with practically no wind. The ceiling was low at 335 m, but visibility was good at 18 km. The conditions at K.I. Sawyer Airbase were similar to those in Marquette except for a mist that was depositing fine particles of snow on the runway. When the groomed, previously tested snow cover on runway 01-19 was examined at 08:00, the air temperature was –6.1°C, the snow temperature was –5.0°C and the pavement temperature under the snow was –5.5°C. The snow was dry and dense, but it consisted of loose particles. There were, however, tracks of compacted and bonded snow made by the aircraft tires during the previous day's runs. There were lumps of snow with diameters up to about 20 mm. It was decided to break the lumps by running a front loader back and forth on the test strip. This operation was completed by about 10:00 when the air temperature dropped slightly to –6.6°C. The grooming process removed the big lumps, but produced a cover that varied in thickness from 10 mm to 25 mm. 'Before Aircraft' ground vehicle tests with the SFT and ERD were conducted on the east lane of the test strip at 10:10.

Table 16a. Results of ground vehicle tests before the aircraft tests on the test section of runway 01-19 in the morning of 7 February 1999

TEST: 9938.1 Before Aircraft

Date: 99/02/07 **Air Temperature:** –6.6°C
Time: 10:10 - 10:15 **Facility:** 01-19
Test Location: East lane of old groomed test strip **Length of Test Strip:** 400 m
Surface Conditions: Compacted snow (12 to 25 mm) at –5.4°C

Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
50	1	0.21				0.27
	2	0.21				0.25
	3	0.19				0.31
	4	0.22				0.31
	Average	0.21				0.29

Table 16b. The run matrix for the test flights on Sunday 7 February 1999 at K.I. Sawyer Airbase on groomed dry snow cover with compacted tracks made during the previous day

Flight	Run	Time	LDG/TO/RTO Configuration	Description	Surface Condition
R097	1	10:18	LDG	80 kn tare run	Both main gears on old tracks of compacted snow (good test for analysis)
R097	2	10:35	LDG	60 kn braking run	Light snow activities, tracks broken
R097	3	10:53	LDG	80 kn braking run	Left gear on east edge where ERD and SFT performed 9938.1 'Before Aircraft' tests
R097	4	11:07	LDG	Max. speed braking run	Braking actions on section with plastic grooves
R097	5	11:27	TO (Spoilers Down)	80 kn tare run	Tracks to bare pavement (see Figure 6)
R097	6	11:50	RTO (Spoilers Up)	80 kn tare run	Difficult to identify
R097	7	12:05	RTO	80 kn braking run	Difficult to identify

Table 16c. Results of ground vehicle tests after the aircraft tests on the test section of runway 01-19 in the morning of 7 February 1999

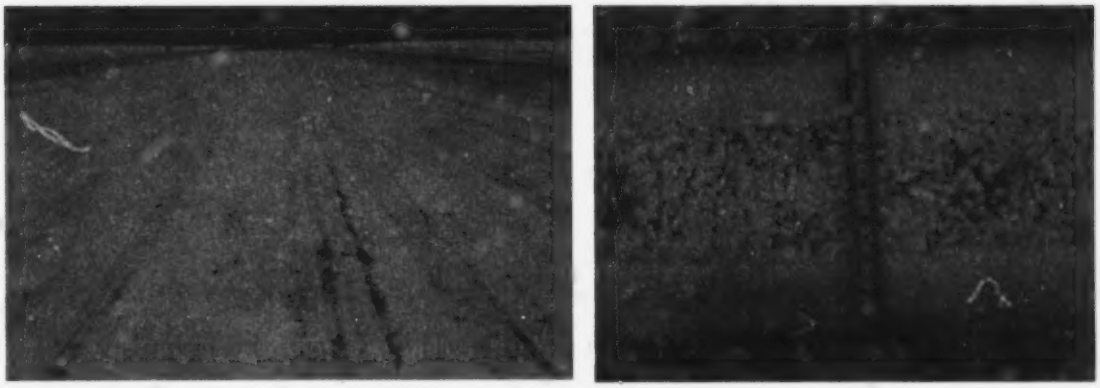
TEST: 9938.2 After Aircraft

Date: 99/02/07 **Air Temperature:** –5.0°C
Time: 12:10 - 12:30 **Facility:** 01-19
Test Location: Between taxiway B and C **Length of Test Strip:** 400 m
Surface Conditions: Compacted snow

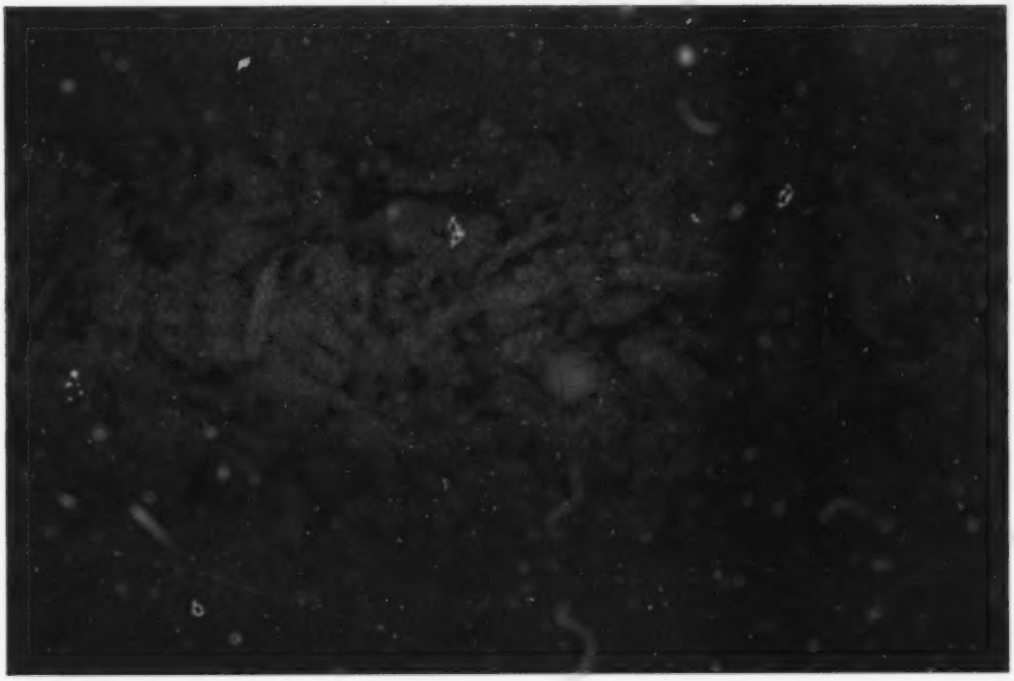
Target Speed (km/h)	Section No.	Test Equipment and Test Tire				
		SFT ASTM (100 psi)	GT ASTM (20 psi)	IMAG PIARC (24 psi)	ITTV AC 26x6.6 (136 psi)	ERD
65 West Side	1	0.18			0.22	0.30
	2	0.18			0.22	0.21
	3	0.19			0.22	0.25
	4	0.19				0.29
	Average	0.19			0.22	0.26
50 Centre	1	0.19			0.24	0.28
	2	0.20			0.24	0.25
	3	0.20			0.24	0.25
	4	0.18				0.27
	Average	0.19			0.24	0.26
40 East Side	1	0.15			0.20	0.22
	2	0.20			0.20	0.28
	3	0.19			0.20	0.23
	4	0.18				0.29
	Average	0.18			0.20	0.26

Between 10:18 and 12:05, several aircraft tests were carried out as listed in Table 16b. After the aircraft tests, the ground vehicles SFT, ITTV and ERD tested the strip used by the aircraft. The results of these after-aircraft tests are given in Table 16c.

Following the completion of the ground vehicle tests, the snow strip was examined visually. A general view of the strip at this time can be seen in Figure 6a. It was impossible to identify the tracks left behind by the aircraft tires in conjunction with their flight numbers. The track left behind by the ITTV test tire could be identified. It was of some interest, as can be seen in Figures 6b and c. In this case, the tire cracked the compacted snow and produced a pattern of ice pellets.



(a) (b)



(c)

Figure 6. Tracks left by the aircraft and the ITTV on runway 01-19 during the aircraft tests and the ground vehicle tests after 12:15 on Sunday 7 February 1999 (a). At 65 km/h, ITTV made a pattern of broken ice pellets in the mid section under the tire (b and c). Snow temperature was –4.4°C

4 CONCLUSIONS AND RECOMMENDATIONS

The low volume of commercial air traffic and the long (3700 m) and wide (20 m or more) uniform asphalt concrete surface of the movement area (taxiway and runway) at K.I. Sawyer Airbase provided an ideal, textbook-type platform for conducting vehicular tests on a winter contaminated surface. Tests could be performed with a number of vehicles at the same time, running on different tracks parallel to each other. This avoided the condition of running the vehicles in sequential manner on previously travelled and disturbed surfaces. One series of tests involving three ground friction devices – IMAG, GT and SAAB – and (incidentally) the aircraft, conducted on freshly fallen snow (on Tuesday 2 February at 15:00), proved the real possibility of conducting such parallel tests. No such tests had ever been performed in the past three years of runway friction tests conducted so far. Unfortunately, since this series was not part of the previously planned test series, friction data were not recorded for comparative purposes. However, the tests showed that the degree of compaction (96%) produced by the IMAG test tires (at 40 km/h) was comparable to that (98%) developed by the tires of the slowly moving (≈ 10 km/h) aircraft main gear. At the speed of 40 km/h, the SFT and the GT respectively produced 74% and 44% compaction. K.I. Sawyer Airbase is certainly a unique facility and should therefore be used in future.

The author would like to make additional recommendations that would improve the test conditions and working environment.

Under real-life operational conditions at major airports, dense snow would not be allowed to build up to a thickness of 10 mm or more and left on the runways longer than the maximum time required to clear them (environmental and operational conditions permitting). During this short time, there could never be a significant morphological change in the snow unless, of course, it was compacted locally by cleaning vehicles or aircraft tires. Melting processes, if present, would increase the water content of deposited snow and make the snow particles rounder, but large aggregates in the form of dense lumps as large as golf balls (found in the groomed snow) would never develop. Nature often produces rounded snow particles, about 1 mm or less in diameter, depending on the ambient temperature, humidity, and the weather conditions. These are often clusters of tiny crystals with inter-particle voids. Consequently, the particles are of lower densities. In short, stored snow and grooming processes should never be used for tests as recommended earlier [7].

Snow on runways and other movement areas relevant to realistic operational conditions should always be used. This will, of course, seriously limit the number of tests that can be carried out during a given time. This could also hamper previously arranged test plans and schedules. However, nature could provide excellent opportunities, depending on weather conditions, if flexible plans are adopted. One ideal opportunity (in fact the best one in the whole week) of using the entire runway, covered with an extremely uniform layer of undisturbed freshly fallen snow, was missed during the morning hours of Saturday 6 February because of the lack of flexibility in planning. This was due to the restrictions on the environmental conditions under which the aircraft was allowed to

perform the tests. A few well-executed tests with documented data on the test conditions and the characteristics of surface contaminants are more useful than a thousand bad ones conducted for unrealistic conditions with little or no information.

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